

Materials Development:

The Advanced Turbines and Engines Program managed by NETL is promoting research on superalloy single crystals providing dramatic improvements in gas turbine performance through increase in working temperature. Among the alloy classes, the so-called third generation superalloys have shown initial promise of permitting operation of gas turbine blades at temperatures even higher than those possible with current alloys, but obtaining the single crystal blades in a defect-free form has been problematic. Researchers at the University of Florida, Gainesville, have developed heat treatment procedures that reduce the number of defects in third generation single crystal alloys. The results of the University of Florida investigations were presented at the Materials Workshop to be held at Greenville, South Carolina, October 8-10, 2001. The spectacular increases in gas turbine performance being achieved are due in no small measure to the development of advanced superalloys. In addition, improvements in alloy composition and processing promise to provide even greater opportunities by making better predictions of material behavior under operating conditions.

In addition, important steps are being taken to reach the goal of optimized coatings for single crystal turbine blades for next generation gas turbines. Turbine inlet temperatures on these advanced turbines could exceed 1,400 EC, requiring components capable of withstanding high temperatures and pressures. Current thermal barrier coatings (TBCs) are susceptible to sintering, phase degradation, and creep at temperatures over 1,200 EC, which results in degraded compliance and insulation efficiency. The lack of suitable materials for vital hot-gas path turbine components — first stage vanes and blades, combustors, transitions and shrouds — remains a critical barrier to the implementation of most advanced concepts in gas turbine technology, particularly those connected with the use of coal-derived fuels.

To address the need for high-temperature durability and corrosion resistance required for coal fuels, an ongoing program is developing protective coatings for hot-gas path turbine components. These include TBCs and environmental barrier coatings for superalloys. Engines developed under FE's now completed Advanced Turbine Systems (ATS) program require TBCs on turbine blades and vanes. The ATS TBCs being employed, based on yttria stabilized zirconia (YSZ), are derived from the airline industry and have functioned well for thousands of hours in relatively clean combustion gas environments. However advances are needed to increase coating durability from less than 10,000 hours to greater than 30,000 hours (on natural gas), and to extend the increased durability to operation on coal-derived fuels.

In land-based gas turbines, surface deposits (glassy dust and sulfate salts) can penetrate into porous TBCs and damage their strain-tolerant microstructure, resulting in premature spalling (chipping or flaking). YSZ-based TBCs also have limited resistance to corrosive attack by sodium sulfate and sodium vanadate salts. These salts can react with the YSZ and attack the metallic bond coating, resulting in premature TBC failure. In next generation turbines, temperature variations of thermal cycling may be just as damaging as long time exposure at temperatures experienced in base load systems.

Undertaking the advanced coating work is a university/industry consortium which administers FE's Advanced Gas Turbine Systems Research Program. The Program began in 1992 and is run by the South Carolina Institute of Energy Studies. Several significant accomplishments in the recent past are accelerating the pace of coatings research undertaken by this group. Investigators at the University of Connecticut, in cooperation with Renishaw, a small business in Illinois, have developed a non-destructive inspection technique, based on photoluminescence phenomena, that can predict incipient failure of TBCs. Renishaw is developing a portable device to inspect coatings on turbine blades.

A team at the University of Pittsburgh has studied two systems that appear promising. One has a bond coat composed of platinum aluminide (PtAl), while the other has a nickel-cobalt-chromium-aluminum-yttrium (NiCoCrAlY) bond coat prepared by argon-shrouded plasma-spraying. The superalloy substrates and YSZ topcoats are identical for the two systems. The thermal exposures in laboratory air include cycling from 1,100 EC to 30 EC once per hour and six times per hour. In the one-hour cycles, the PtAl system typically failed in about 1,000 hours, while the NiCoCrAlY system failed in about 300 hours. Thus, for the one-hour exposure conditions, the PtAl bond coats were much more durable. Conversely, in the more rapid cycling conditions (six times per hour), the time to spallation for the PtAl system was cut in half to about 500 hours and for the NiCoCrAlY system was essentially doubled to about 700 hours. So under more rapid cycling, the relative ranking of the two coatings was reversed. The type of thermal exposure employed also resulted in significant changes in the degradation microstructures of the coatings. Results suggest that anticipated duty cycles affect the choice of TBCs, and that comparison of experimental results between laboratories requires detailed specification of the exposure conditions used.

Ongoing coatings research is aimed at improving the stability of the bond coatings and TBCs, with emphasis on a systems approach. The first goal is a reliable TBC system with a 1,300 EC capability for a minimum of 5,000 hours to be achieved by December 2002.